

Zero Emission Cargo Transport ZECT 1 San Pedro Bay Ports

Vehicle Technologies Office Annual Merit Review
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[Project ID # ELT 115]

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ZECT I Overview

Timeline

- Project Award: 8/12
- Contractor Kickoff: 11/12
- Project Completion: 9/30/18

Contractors & Projects

- TransPower – Battery Electric and Series Hybrid Drayage Trucks
- US Hybrid – Battery Electric and Parallel Hybrid Drayage Trucks
- NREL – Data Acquisition and Analysis

Acknowledgements

- UC Riverside
- Fleet Operators: TTSI, Cal Cartage, Three Rivers Trucking, NRS, SA Recycling, Knight Transportation Services, Pasha Stevedoring and Terminals, BAE Systems, and Terminalift

Barriers & Challenges

- Evaluate Performance and Reliability
- Promote Market Acceptance
- Data Collection and Analysis

Budget

- DOE: \$4,169,000
- Cost Share: \$5,205,641
- Total Cost: \$9,374,641
- DOE Expended: \$3,945,212

Relevance: Goals & Objectives

- **Project Objectives:**

- Complete vehicle builds
- Complete demonstration with Fleet Operators
- Complete data collection and analysis

- **Results:**

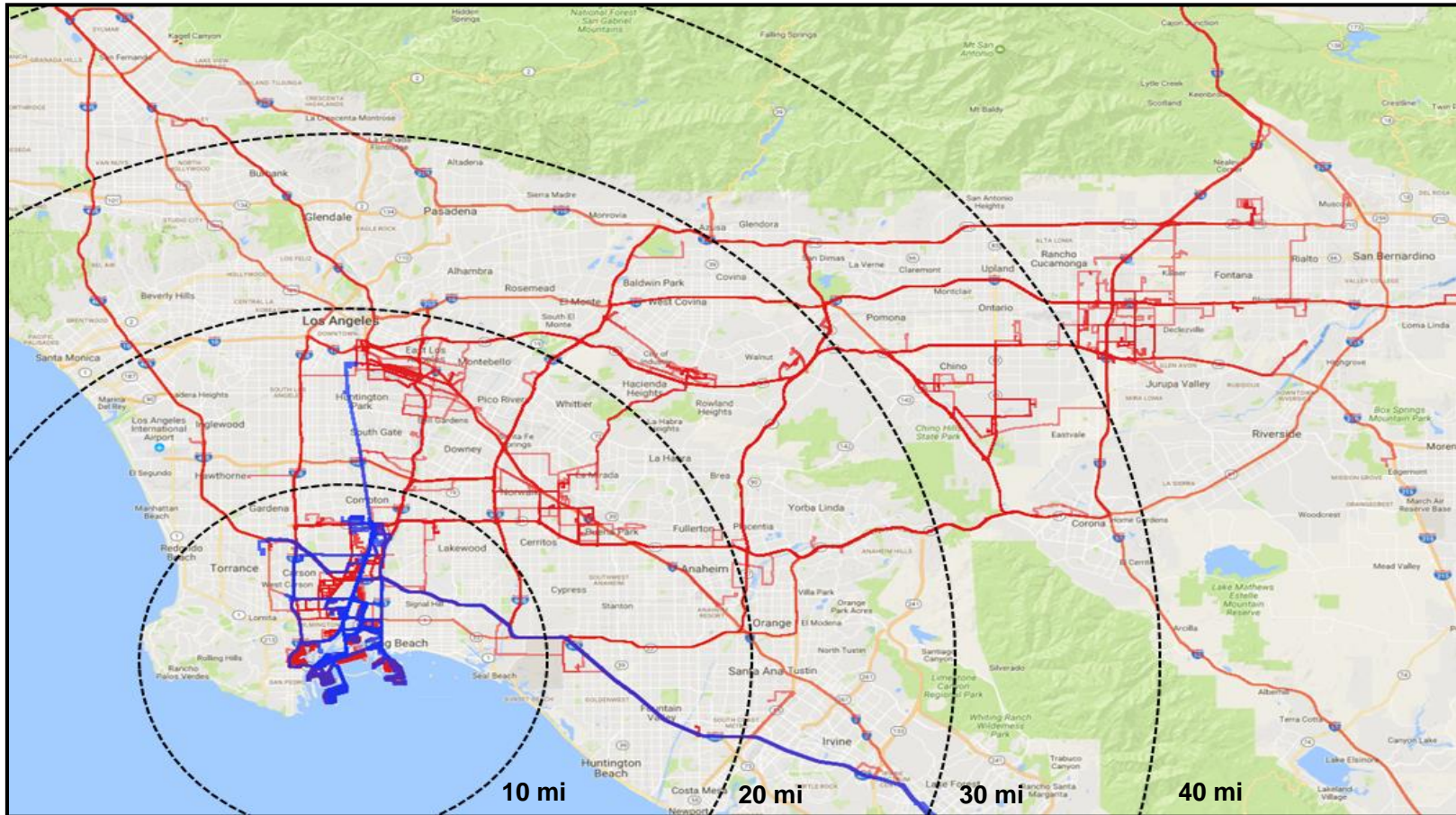
- All four vehicle platforms completed
- Demonstration completed for one platform, in progress with remaining three
- Data collection completed for one platform, in progress for remaining three

- **Impact:**

- **Technology advancement and demonstration and deployment of Zero Emission Technology in Drayage service in California**



Technical Progress: Operating Range



Technical Progress: Technologies

	BET		PHET	
Developer	* TransPower	US Hybrid	TransPower	US Hybrid
No. of Trucks	4	2	2 - Series Hybrid	3 - Parallel Hybrid
Chassis	International Prostar	International Prostar	International Prostar	Peterbilt 384
Traction	Dual IPM Motors	Induction Motor	Dual IPM Motors	IPM Motor
Motor	300 kW	320 kW	300 kW	222 kW (402 kW total)
Transmission	Automated Manual	Direct Drive	Automated Manual	Automatic
APU Displ./Fuel	N/A	N/A	3.7L / CNG	8.9L / LNG
APU Power	N/A	N/A	65-110 kW	180 kW
Battery/Fuel Storage Capacity	215 – 315 kWh	240 kWh	138 kWh	80 kWh
			60 DGE	72 DGE
Charger On-Board	70 kW	60 kW	70 kW	20 kW
Recharge/Refuel Time	2.5-4 hrs	3-4 hrs	2 hrs	3-4 hrs
			10-15 min	10-15 min
Drayage Range (miles)	75-100 (@215 kWh)	70-100	250+	250+
	110-150 (@ 315 kWh)		35-50 AER	30 AER

* Project completed



Technical Progress: TransPower BETs

- Project completed September 2017
- Four Electric Drayage Demonstration (EDD) trucks built, EDDs 1 – 4
- EDDs 2,3,4 maintained demonstration efforts
- Matched performance of baseline diesel in power, torque, load handling
- Achieved higher reliability than previous generation of Class 8 BETs
- Zero emissions and higher energy efficiency
- Drivers responses:
 - performance and quietness favorable
 - range and recharge time less favorable
- Cumulative Vehicle Performance Data (NREL)
 - 579 days; 2660 hrs; 25,786 miles; 44.6 miles/day (avg.)
 - 60-70 mile range full load, single charge
 - 2.13 kWh/mi average efficiency; 17.7 mi/DGE (calc.)
- After Project Life
 - EDDs 1,2,3,4 to continue drayage operations with TTSI
 - EDD 1, 3, and 4 to be upgraded with fuel cell range extender and NMC batteries



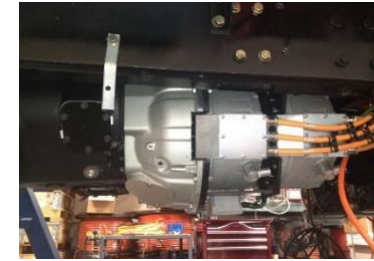


Technical Progress:

TransPower BETs (cont.)

- Incremental improvement

- Automated Manual Transmission
- High power on-board AC charging
- Efficient drive system packaging
- Telemetric data analysis



Dual motors
installed in tandem.



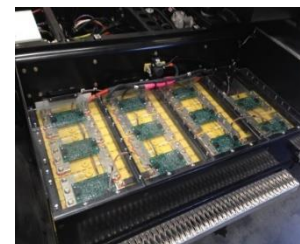
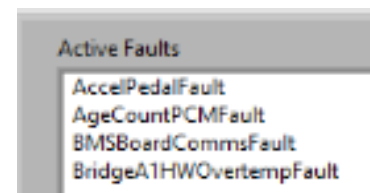
10 speed AMT

- Three generations of battery technology

- Lithium iron phosphate (LFP) still functioning in EDD2/3/4
- 60% higher efficiency LFP installed in EDD1 in 2017 – experimental product whose use has been curtailed due to quality concerns
- Nickel Manganese Cobalt (NMC) batteries to replace LFP in EDD 1, 3, and 4 (along with addition of fuel cells)



Inverter-Charger



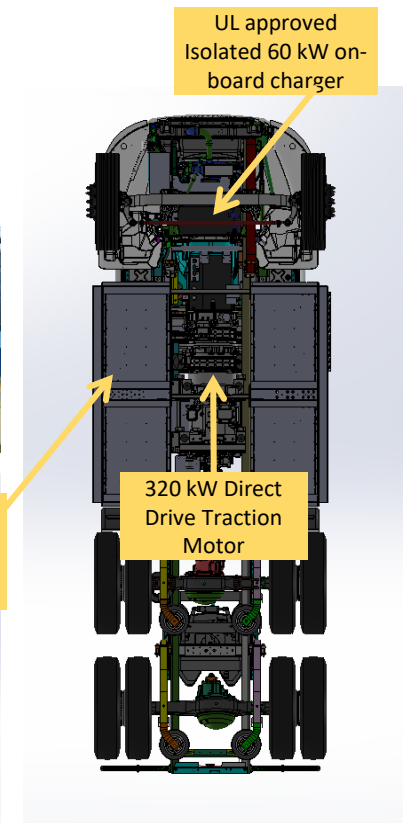
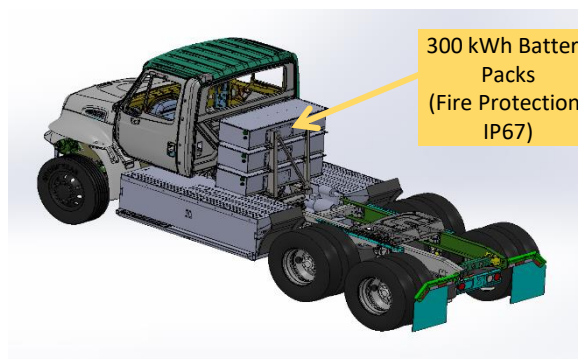
Li Ion batteries & BMS



Technical Progress:

US Hybrid - BETs

- Two BETs in Project
- First BET delivered to TTSI in Q2 2016
 - LFP battery; 300 kWh ; 11 packs in parallel
- Performed pre deployment chassis dyno testing at UCR Q1 2017
- 48 days & 412 hrs. of operation
- 1,479 miles of usage
- 2.2 kWh/mi average efficiency
- Second BET to TTSI in Q2 2018
 - A123 Li – NMC
 - 30% higher energy density
 - 6 packs in parallel
 - 360V to 600V operation

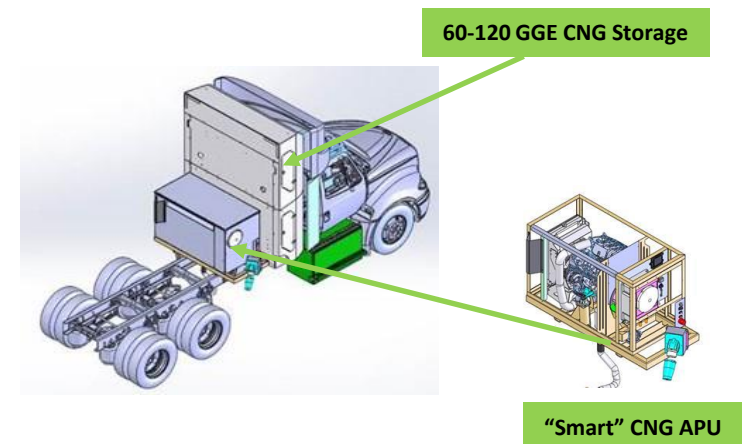




Technical Progress:

TransPower - PHET

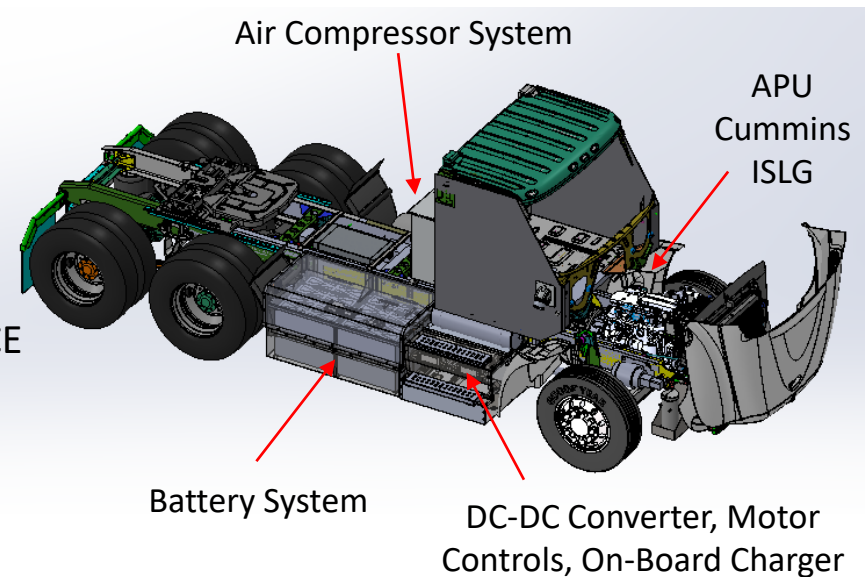
- Two PHETs in Project
- First PHET completed in 2017
- Series Hybrid architecture based on EDD drive train
- APU: 3.7L Ford SI; CNG; 65 – 110 kW
- Hybrid system optimized with APU dynamometer
- Design/Performance:
 - 2.6kWh/mi for 8 hr. drayage shift
 - 100 mile range extension (~150 miles total)
 - min 32.5kW over 8hrs or 62kW ~50% duty cycle
 - 3.5kWh/mi highway (40% more than typical drayage)
 - Bridge climb (6% grade)
- Lessons Learned
 - Smaller battery design requires 80-120kW from APU
 - ST Engine output is capped in firmware to 62kW
 - AT engine should achieve 110-120kW peak
- First PHET to conclude testing Q2 2018; commence deployment Q3 2018
- Second PHET, upgraded with NMC batteries; commence deployment in Q3 2018
- CEC funding to upgrade first PHET with larger APU and larger NMC battery pack in 2019-2020



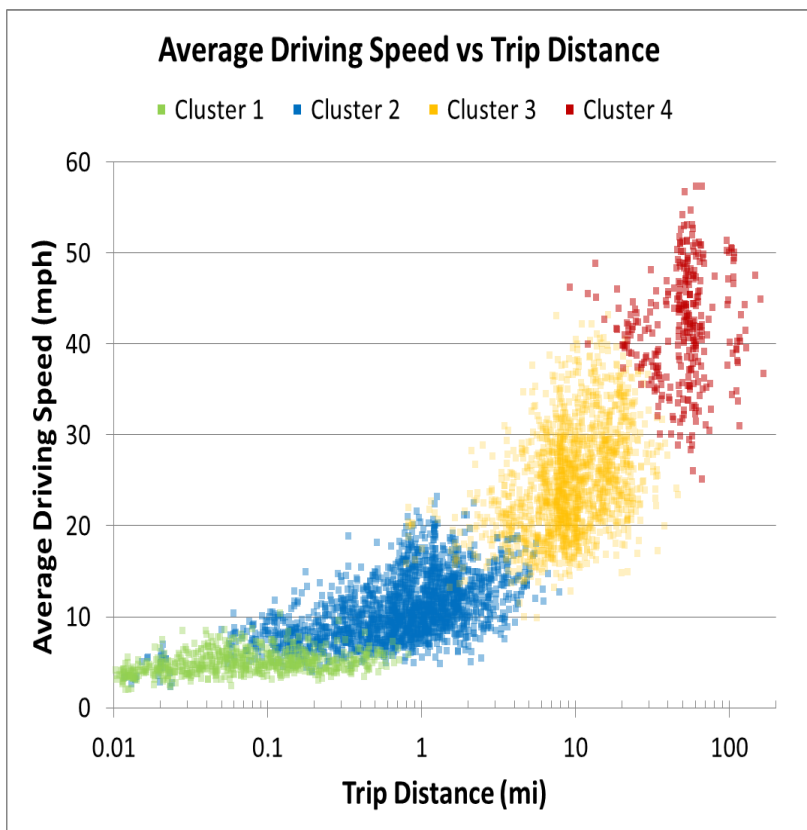


Technical Progress: US Hybrid - PHETs

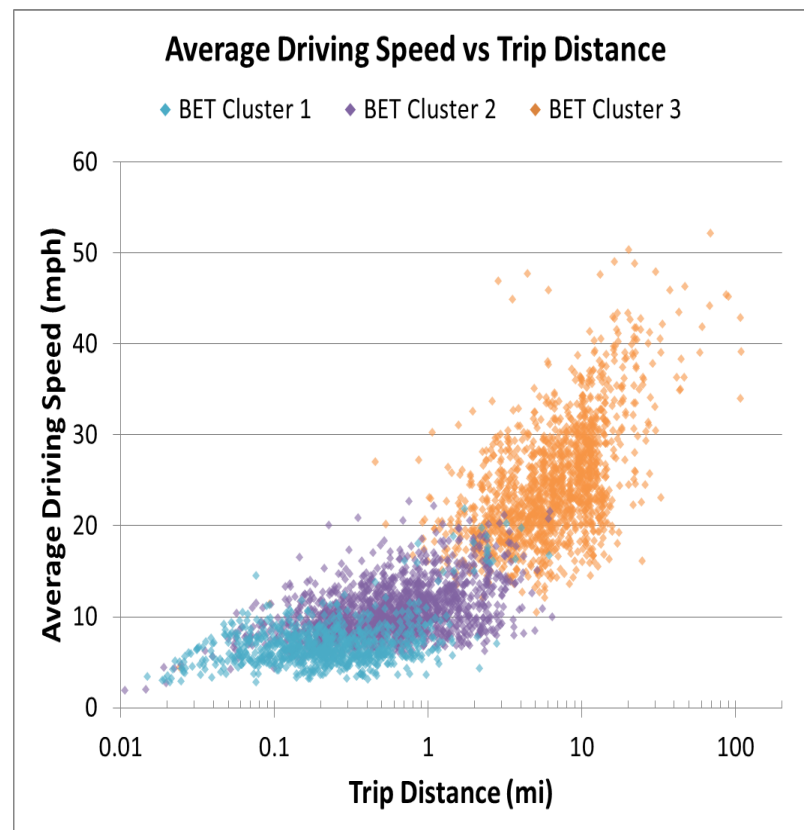
- Three PHETs in Project
- Three Trucks completed; Two in demonstration
- Parallel hybrid architecture
- APU: 8.9L Cummins ISLG SI; LNG; 180 kW
- PHET tested at UC Riverside chassis dynamometer
- Design/Performance
 - Power and Torque comparable to ISX12 or ISX15
 - 30 miles AER (250 miles total)
 - Positive Driver Feedback
- Hybrid Control Unit (HCU)
 - Seamless transition from All Electric to Hybrid
 - Senses load and battery charge level to engage ICE for motive and electrical power
 - Electric only during queuing and traffic
- 185 days; 7,167 miles of usage
- 3.87 kWh/mi average efficiency



Data Analysis: TransPower BET



Conventional Diesels



BETs

Data Analysis: TransPower BET

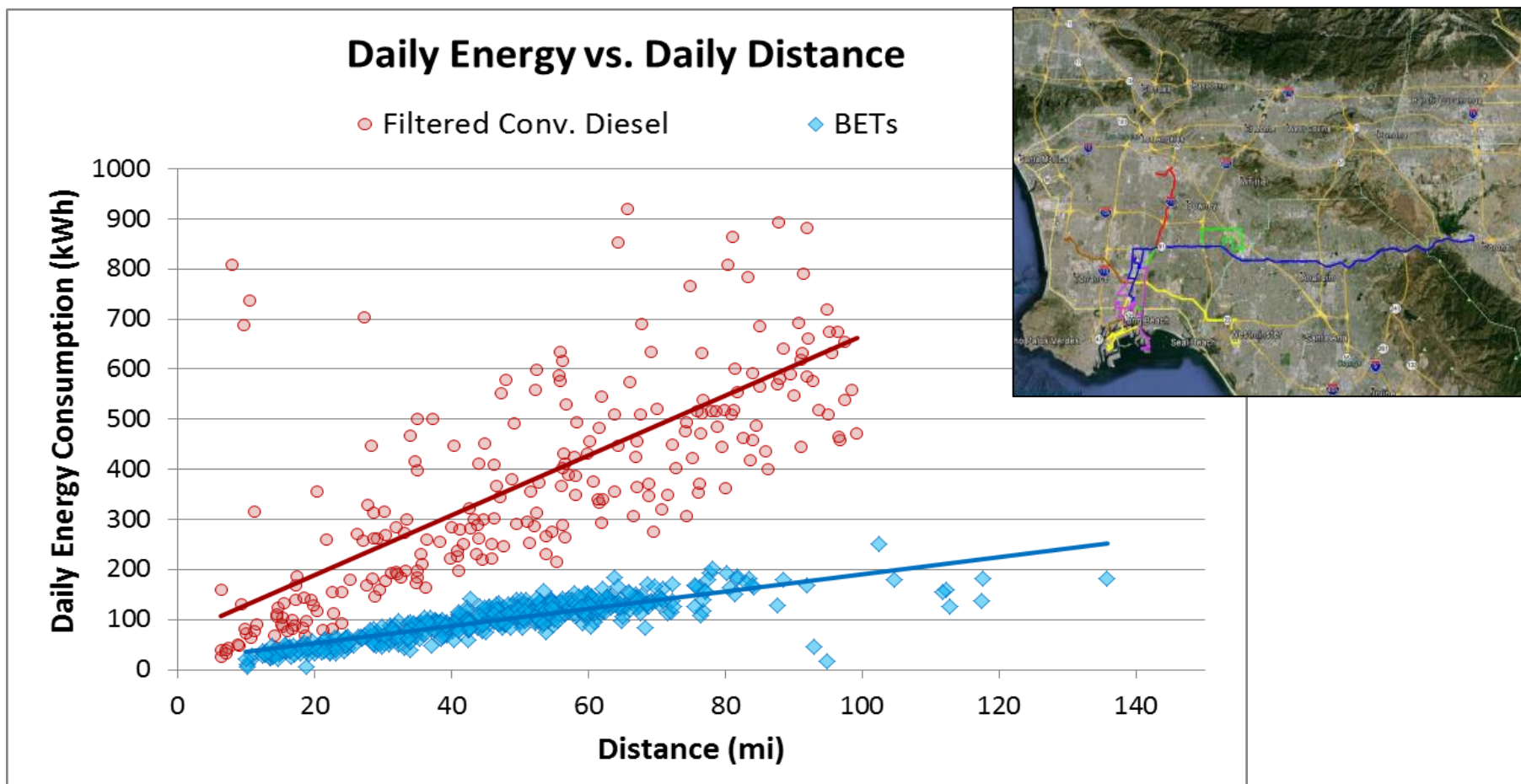
Average Cluster Statistics

BET	Cluster 1	σ	Cluster 2	σ	Cluster 3	σ
Number of Trips in Cluster	884	N/A	1,578	N/A	1,495	N/A
Total Distance (%)	2.10%	N/A	9.20%	N/A	88.70%	N/A
Average Trip Length (mi)	0.34	0.46	0.84	0.78	8.53	8.59
Average Driving Speed (mph)	6.82	2.41	10.44	2.81	24.63	6.76
Average Total Speed (mph)	2.51	1.16	5.87	2.68	17.22	7.57
Average Stops per Mile	24.99	18.7	7.95	5.62	2.12	1.67
Average Kinetic Intensity (1/mi)	59.62	19.88	17.03	9.13	1.85	1.6

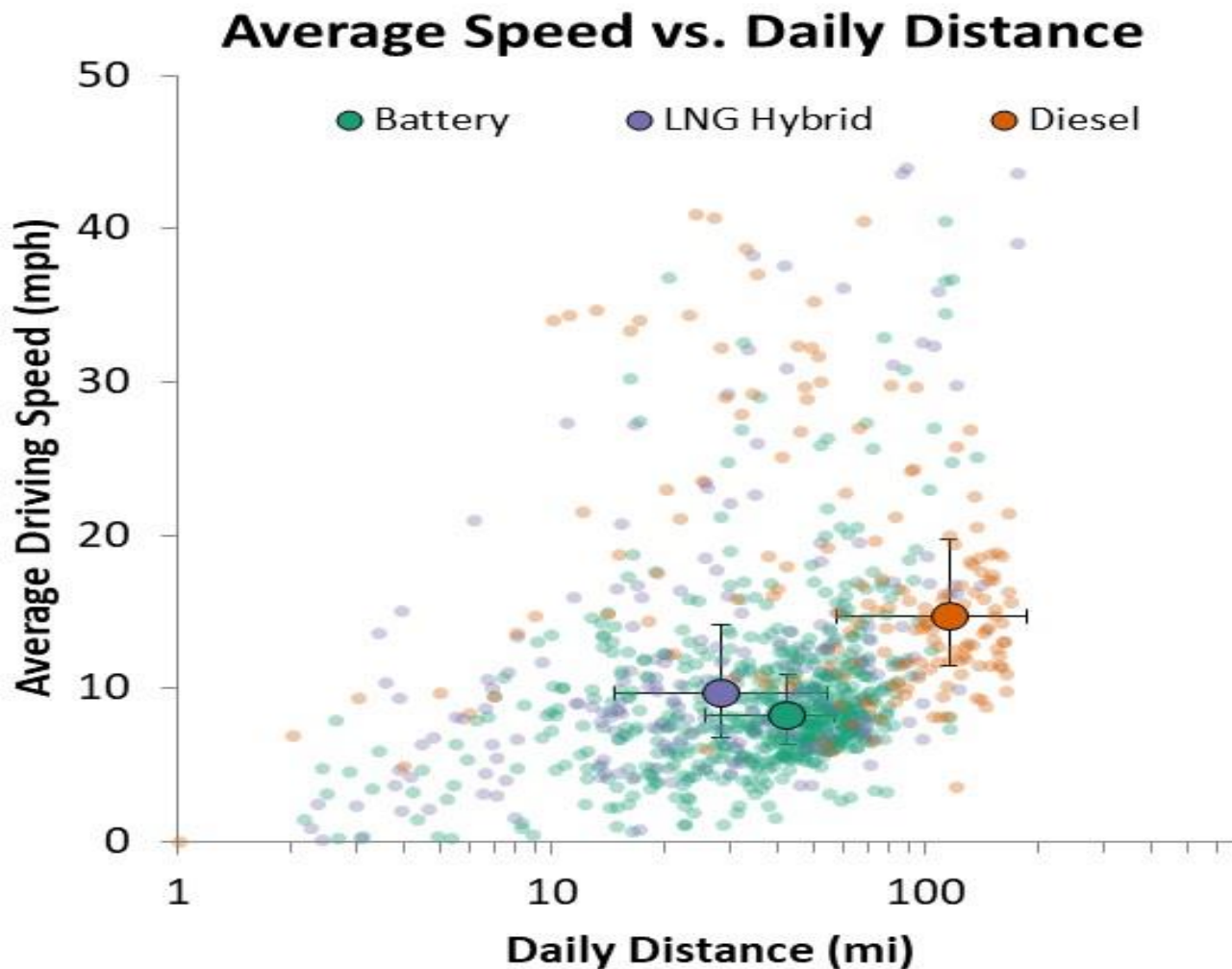
DIESEL	Cluster 1	σ	Cluster 2	σ	Cluster 3	σ	Cluster 4	σ
Number of Trips in Cluster	625	N/A	1874	N/A	1551	N/A	314	N/A
Total Distance (%)	0.2%	N/A	5.7%	N/A	48.8%	N/A	45.3%	N/A
Average Trip Length (mi)	0.12	0.13	1.06	0.92	11.05	6.43	54.93	25.39
Average Driving Speed (mph)	4.90	1.20	10.76	3.38	24.81	5.74	41.76	6.08
Average Total Speed (mph)	0.94	0.70	4.33	2.87	14.74	6.61	32.53	8.34
Average Stops per Mile	20.15	15.57	5.53	3.97	1.41	0.92	0.28	0.18
Average Kinetic Intensity (1/mi)	55.10	22.17	8.84	6.45	0.94	0.50	0.24	0.09

Data Analysis: TransPower BET

Daily Energy Consumption



Data Analysis: Project Totals to Date



Data Analysis: Project Totals to Date

Daily Averages

Median Daily Values	Conventional	EDD2-4	US BET	US LNG
Operating Time, hr	7.85	5.09	8.59	3.92
Distance, mi	124.15	43.81	23.47	34.45
Average Energy Efficiency, kWh/mi (or eqv.)	6.12	2.13	2.2	3.87
Average Regeneration Energy, kWh	N/A	17.26	No Info	38.04
Average Speed, mph		9.56	3.23	9.4
Average Driving Speed, mph	16.5	19.77	18.58	19.83
Average Idle Time, hr	2.6	2.87	7.47	1.82
Average Idle Time > 5 min, hr	1.1	1.59	6.12	0.97
Average Start SOC, %	N/A	91.24	81.5	56.63
Average End SOC, %	N/A	54.66	73.75	54.38
Average Median Motor Temp, °C	N/A	40.32	39	58.25
Average Median Electronics Temp, °C	N/A	38.59	35	45.5
Time on Charge, hr	N/A	9.61	2.94	0.52
Average kWh per Charge, kWh	N/A	101.65	39.23	0.16
Average Air Cond Energy, kWh	N/A	3.08	No Info	0.42

Response to Reviewers Comments

The reviewer reported this project supports the overall DOE objective of petroleum displacement. By demonstrating hybrid and battery vehicles side-by-side with conventional vehicles in a real-world business, a good apples-to-apples comparison can be seen. It helps promote the fuel efficiency gains past an engineering simulation to a real-world usage case, which should help lead to less resistance to adaptation. Fleet operators put more faith in real-world business case return on investment data, than on an engineering estimate. (Reviewer 1)

Real-world demonstration of new technology with end users is a critical component to improve and promote the technology. The Ports region of southern California provides a unique opportunity to demonstrate new on- and off-road alternative energy mobile source technologies. The Ports offer mobile source technology developers with experienced fleet participants, varying duty-cycles and load demands, and proximity to an array of alternative fuels and electric charging infrastructure. The Class 8 Drayage truck and fleet operators in this project are utilizing the technology in their everyday operations, gaining better awareness of alternative motive power technologies, alternative fuel and recharging infrastructure, exploring ideas to better manage and incorporate these technologies into their operations, and communicating this information to technology developers.

The reviewer commented that progress is good for initial battery electric trucks (BETs), although it would be great to convince fleet partners to plan truck use to maximize range. The project could use yard bulldog to move the trailer while the cab is charging, this example should increase usage percentage of vehicle. The reviewer suggested a second BET will help identify impacts of architecture and component sizing to performance. Hybrid electric vehicle (HEV) truck progress is vital, particularly in clusters three and four to better understand architecture, component sizing and selection. (Reviewer 3)

The project concept was to develop zero-emission technologies for Class 8 drayage operations and demonstrate these technologies in real world application. The project has achieved that objective and has helped to further the knowledge base of both technology developer and prospective users of the technology. The project has demonstrated where technology and the users of that technology may need to make necessary adjustments for the most effective use of the technology. Vehicle operators find the performance and quietness of the technology very appealing. Increased energy capacity and shorter recharging will help significantly. HET demonstrations are vital to determine the right balance of APU to electric power in real-world applications.

Remaining Challenges and Barriers

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- **Evaluating Performance and Reliability:**
 - Continue data collection and analysis of vehicle performance of battery electric and plug-in hybrid electric trucks
 - Continue emissions testing for plug-in hybrid electric trucks
- **Market Acceptance**
 - Addressing fleet operator range anxiety of battery electric trucks
- **Costs: batteries and drive systems**
 - Costs/kWh of batteries expected to continue to fall with expanding market
 - Improvements in on-board charging will reduce charging time
 - Improvements in drive system efficiencies increase range

ZECT I Summary

- BETs – one project complete; both show comparable performance
 - TransPower - completed
 - EDD 2 to continue service with Drayage operator with LFP batteries
 - EDD 1, 3, 4 to be retrofitted with higher energy NMC batteries and fuel cell range extenders in Q4 2018 under CEC project
 - US Hybrid - Both trucks continuing demonstration and data collection
- PHETs - platforms demonstrating Class 8 capabilities
 - TransPower – one scheduled for deployment; one in process of completion
 - First PHET to be upgraded with larger engine/APU and NMC battery pack under CEC project in 2019-2020
 - US Hybrid - two trucks in demonstration; one truck used in testing
 - Systems optimization and emissions testing to be completed
 - Four PHETs to be built and deployed with NZE L9N under POLB contract

